The APS Roadmap Development Process and Background Information

Dean Haeffner
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Introduction

Recently, a memo was distributed to the APSUO Steering Committee, PUC Executive Committee, and APS/XSD group leaders, and through them to the broader user community, from Dennis Mills, laying out a possible roadmap for future configuration of beamlines at the APS. This follow up document provides additional information on the process and technical details that went into developing that proposal. The roadmap has generated much comment from the user community, and it is clear that additional clarification on how we arrived at this draft version is needed. We hope to provide some of that clarification here.

Process

The process of gathering input on future directions for the APS has been going on for several years. Various efforts have been made to reach out to staff, resident users, partner users, general users, and advisory panels, as well as gathering feedback from the DOE on a regular basis. Explicitly, "medium-term" beamline proposals were solicited for upgraded APS beamlines from both XSD staff and CATs in early 2008. Forty-three such proposals were submitted, ranging from relatively modest proposals for instrument and detector upgrades to proposals for entirely new beamlines. These proposals are archived on the APS Upgrade webpage

(www.aps.anl.gov/Upgrade/Resources/Planning/Beamlines/index.html).

A similar call went out for upgrades to the accelerator, with dozens of proposals being submitted in that area as well.

Separate from the Medium Term process, several groups have developed plans for new beamlines following the established APS process. Submission of Letters of Intent (LOIs) and subsequent Scientific Proposals for new beamlines at the APS has been the mechanism for allocation of beam ports since the beginnings of the APS. Both the LOIs and Scientific Proposals are reviewed by the APS Science Advisory Committee (SAC). The various beamlines (both new and significant upgrades) proposed in LOIs and Scientific Proposals were integrated with other input to develop the beamline proposals for the APS Upgrade.

To gather broader user input, an APS renewal workshop was held in October 2008 in Lisle, IL. One outcome of this workshop was ten science case reports from the workshop's working groups in the areas:

- Chemical science and engineering,
- Condensed matter and material physics,
- Engineering applications and applied science,
- Fundamental interactions in chemical, atomic and molecular physics,
- Geological, environmental, and planetary science,
- Interfacial science,
- Life sciences (excluding MX),
- Macromolecular crystallography,
- Materials science and technology, and
- Polymers and soft materials.

These reports can be found at:

www.aps.anl.gov/Upgrade/Resources/Planning/Science_Cases/Reports/

Following the renewal workshop, the whitepaper "Renewal of the Advanced Photon Source" was submitted to the DOE (Oct. 29, 2008). In this whitepaper, the dual themes of "Mastering hierarchical structures through x-ray imaging" and "Real materials in real conditions in real time" were presented and developed. The themes were further developed along the lines of six scientific drivers in the "Strategic Renewal of the Advanced Photon Source: Proposal for approval of Conceptual Design (CD-0)" submitted to DOE on May 31, 2009.

The result of the input efforts and the refinement from the whitepaper and Critical Decision Zero (CD-0) proposal was the production of a body of information containing many worthwhile ideas that merit serious consideration. To help review and distill the various proposals, the APS management formed six working groups in the CD-0 scientific driver areas made up of one APS staff member and one or two outside experts. The APS and external area leaders are shown in Table 1. The groups sifted through the input, updated the information, put the data on a comparable basis, and assigned all proposals to one of the six scientific driver categories. A seventh temporary theme ("Atoms to Automobiles") was added for projects that did not easily fall into one of the six areas. The projects in this area were later merged back into one of the original six areas.

Table 1

Category	**APS Leader**	**Outside Co-Leader(s)**
Imaging/Coherence	Barry Lai	C. Jacobson & Mark Sutton
Extreme Conditions	Malcolm Guthrie/ Wolfgang Sturhahn	Mark Rivers

Ultrafast Dynamics	Eric Dufresne	Paul Evans
Interfaces	Paul Zschack	John Budai & Dillon Fong
Spectroscopy	Steve Heald	Clem Burns
Proteins to Organisms	Stefan Vogt	J. Penner-Hahn & Malcolm Capel
Other (Atoms to Automobiles)	Dean Haeffner	

For each of the scientific areas a community input meeting was held to get feedback and to raise the awareness of the renewal/update process. After further refinement, the APS area leaders presented the proposals to the APS SAC at the October, 2009 SAC meeting.

The APS management took the input from all of the various sources, especially the comments by the APS SAC, and used it in preparing CD-0 Mission Needs presentations given by Murray Gibson and Geoff Pile to DOE/BES on December 11, 2009. This was part of a long series of communications between the upper management of the APS and Argonne and the relevant DOE/BES officials to help prepare the internal DOE CD-0 document. In the presentations, four potential upgrade scopes were described (see Fig. 1), with options 2 or 3 being the options that most closely fit the current proposed budget. In options 2 and 3, a list of "Flagship" beamline projects was proposed (see Tab. 2). A subset of the flagship beamlines are designated as "key" beamlines and are to be considered the highest priority of the flagships (denoted in bold). Note that one of these, the Bionanoprobe, is a special case. Its mission falls largely outside the DOE/BES mission, and the APS will seek funding from other agencies to help finance this project, so its cost may fall outside of the APS Upgrade budget.

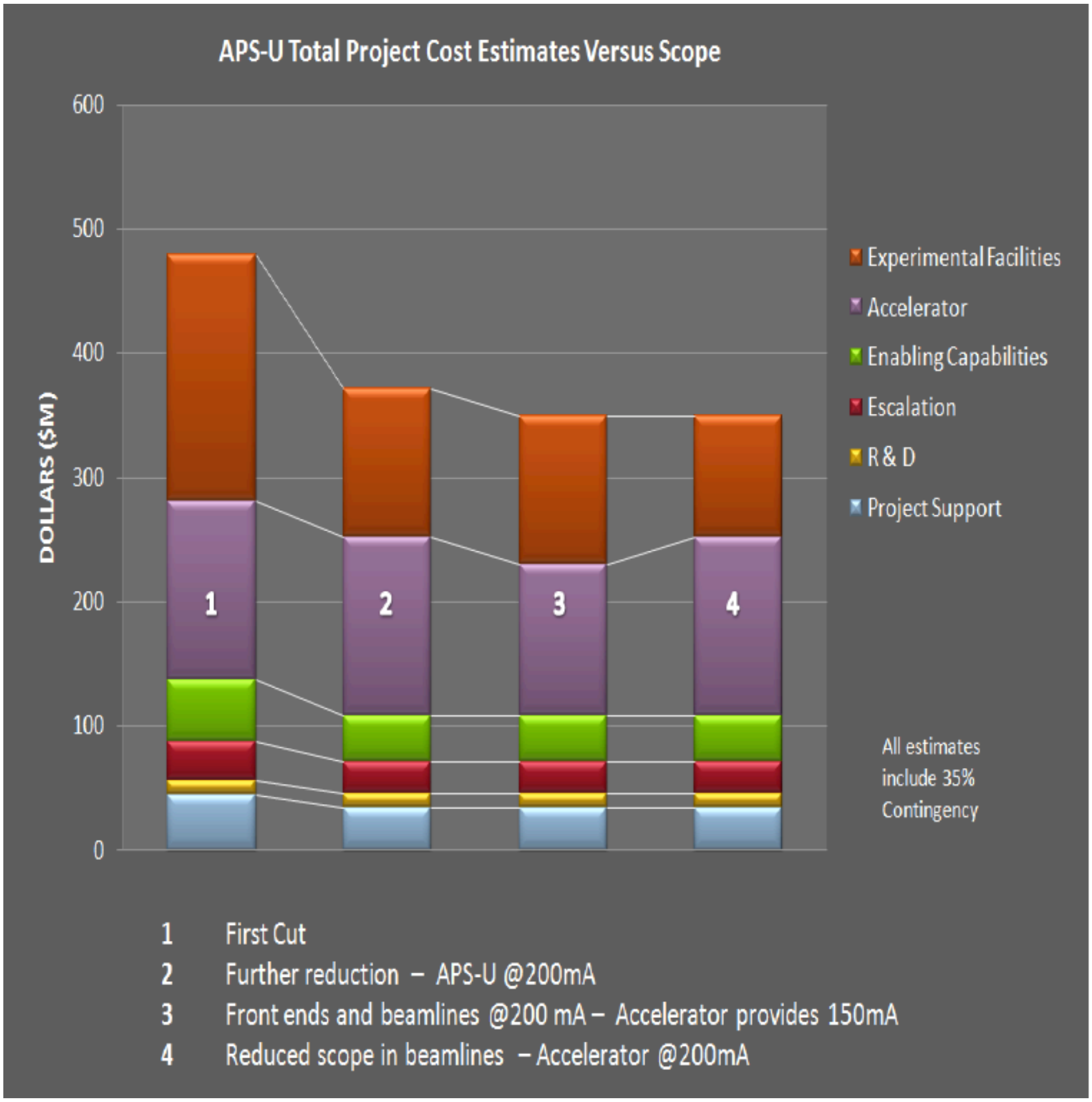

Figure 1. APS Upgrade scope scenarios.

Table 2. Flagship Beamline Projects

Wide Field Imaging (AXI-WF) (200 m beamline)
Coherent Diffraction Imaging (AXI-CDI)
Surfaces and Interfaces Beamline (XIS)
High Magnetic Field Diffraction Facility (In-field Diffraction)
High Energy X-rays for Mechanical Behavior Upgrade
Advance Spectroscopy (LERIX/XAFS)
High Energy Tomography
Bionanoprobe
Short Pulse X-ray Beamline (SPX)
Enhance X-ray Photon Correlation Spectroscopy (XPCS)
Enhance Ultrafast Imaging
Enhance SAXSB
Split MERIX/HERIX, combine MERIX programs
Nuclear Resonant Scattering upgrade
Catalysis Center Beamline
High Pressure Microbeam Upgrade
Upgrade 100 ps time resolved program
Beamline upgrades for higher storage ring current (as needed at all APS beamlines)

Roadmap Scenario Development

One of the major challenges in the conceptual planning of the APS upgrade is to take the plethora of worthwhile beamline proposals, especially the key flagship proposals, and mesh them with the current layout of the APS. In many ways, it is considerably more challenging to merge new capabilities into an existing, operating facility, than to outfit a new, green field facility. This is especially true when the existing facility and its individual beamlines are operating very successfully with large, productive user groups at nearly every beamline. Any major upgrade of the APS beamlines, especially an upgrade that implements new capabilities, will require careful planning to avoid major disruptions. A clear roadmap for the APS is needed that incorporates the APS upgrade plans but does not preclude other future enhancements of APS beamlines.

Towards this end, a small group of APS staff (Dean Haeffner, George Srajer, Mark Beno, and Dennis Mills) undertook the task of developing roadmap. Iterations of the plan were given to Murray Gibson for feedback, and with less frequency, to the APS Upgrade Steering Committee. Michael Borland provided extensive technical input on aspects concerning the accelerator. The result of this effort was the “strawman” roadmap that is the subject of this document. Before, detailing the aspects of the roadmap, the major factors that entered into the design will be described.

First among the factors is that there are currently only three open ID ports at the APS. As part of the midterm proposal process, 12 new ID beamlines were proposed and several more have been proposed in various other forums. In the flagship list, four beamline projects were designated as "new" beamlines and, additionally, it has been decided to reserve one of the remaining ports for pending outside projects, i.e., either Dynamic Compression (DC)-CAT of Nuclear and Radiological Research (NRR)-CAT. As it was not part of the upgrade plan to eliminate any of the current beamline programs or capabilities, at least two ID ports needed to be "liberated" to accommodate the beamlines proposed in the CD-0 manuscript. One possible way to recover ports is to organize and consolidate similar programs that currently exist at different beamlines. A legacy of the APS is that many beamlines started out as CATs and then transitioned to the APS/XSD. This resulted in duplicate/similar programs existing around the ring. Also considered was placing an experimental program at 35-ID, which is currently used for accelerator diagnostics. In principle, the diagnostics program could share with a scientific program that could coexist with a compatible scientific program. However, after considerable effort, we were unable to find a good match and decided to leave 35-ID as it is for now.

Secondly, a prominent feature for the accelerator in the APS Upgrade is the implementation of long straight sections. The technical details of the LSS will not be given here, but, basically, two quadrupoles are removed to allow the current 5-m straight sections to be altered to 7.7-m straight sections. This extra straight section length is attractive in three ways:

- An extra undulator of the same period can be added, to effectively give a 7.7-m long device.
- An extra undulator of different period can be added to allow peak brilliance at different fundamental energies. This strategy can allow the use of shorter period devices that provide higher brilliance, but no one device with complete spectral coverage. Selecting devices of different periods for different energy ranges can close the gaps in the spectrum. This also is a strategy that can help effectively manage the heat load from the undulators.
- In a canted beamline, part of the straight section is used to make the cant. This necessarily compromises the ID capacity of that straight section and generally requires shorter devices for both branch beamlines. Also, it is very difficult to have more than one device for a branch. An LSS considerably reduces that compromise.

The CD-0 proposal has eight straight sections being converted to LSS. It is also possible to create "pseudo-LSS" by turning off the power to the quadrupoles. The quadrupoles are still physically in the straight section, but the beam does not interact with them (this is how current accelerator studies on LSS have been conducted). A pseudo-LSS does not impact the budget, and such a straight section could potentially be converted to an actual LSS in the future when funds become available.

According to the results of accelerator lattice studies (as of when the roadmap was being developed), LSS need to be placed in symmetric locations around the ring to prevent significant emittance growth and to preserve a 16 mA single bunch current capability. Several symmetries are possible (e.g., every fifth sector–1 X 8, a pair of LSS every 10 sectors–2 X 4, etc.). Several details need to be considered in allocating an LSS to a particular straight section. For example, reduced horizontal beta mode (RHB) is not compatible with a LSS. So, a beamline that requires that mode (such as the AXI-WF imaging beamline) should not be placed on a LSS sector.

Looking at the various constraints (some will be described below) it was decided that the most attractive configuration is a LSS pair with one normal straight section between them, replicated eight times around the ring in a symmetrical way. This configuration, denoted as "LsL" ("Long", "short", "Long") is schematically shown in Fig. 2. Of the 16 LSS, initially half would be physically implemented and the other half would be pseudo-LSS.

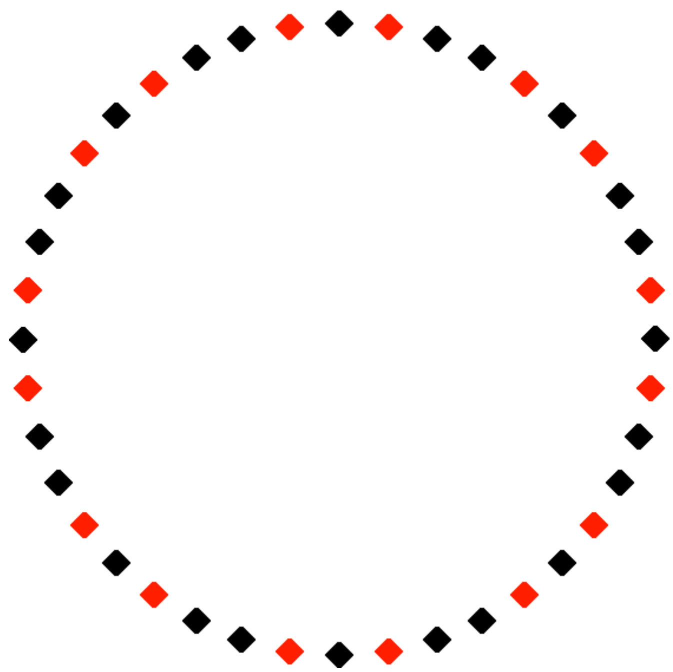

Figure 2. Schematic of LsL long straight section layout.

The third major factor was the desire to have at least one beamline of approximately 200-m length at the APS. This requires the beamline to extend well past the experiment hall and out into the area surrounding the current buildings. There are several places to extend an APS beamline just outside the LOMs, but further extension runs into issues with existing roads, wetlands, buildings, etc. Three ports are the most attractive for a 200-m beamline and they are located at sectors 18, 19, and 20. These three ports are all currently in use and to make room for a long beamline, the current programs would have to be moved to different locations. To further complicate the matter, only one of these beamlines (20-ID) is operated by the APS.

Fourthly, a major feature of the upgrade is the implementation of the SPX project to create x-ray bunches of picosecond length and the corresponding beamline instrumentation to use them. The current plan is to implement one SPX sector and to provide an upgrade path for a neighboring sector if further capacity in this area is needed in the future. The short pulses are created by insertion of two "crab cavities" into the storage ring surrounding the SPX beamline or beamlines. The upstream crab cavity can be placed at the downstream end of straight section preceding the SPX sector(s), or at the upstream end of the first SPX sector. The converse is true for the downstream crab cavity. Each crab cavity takes up approximately half of a 5-m long, so obviously both cannot be placed in the same sector because such a straight section would have no room for IDs. Therefore, it is necessary to affect at least one of the neighbors of an SPX sector. Because of this, it is highly desirable to place the crab cavities in a LSS, which in part dictates the choice of the LsL LSS configuration described above.

A small building adjacent to 7-ID was built as part of a previous SPX related project, and the 7-ID beamline is the home of a current ultrafast x-ray program, so this is the most obvious place for the SPX program, though it is not the only possible site. Given this, the LSS symmetry was fixed to have a LSS at sector 6 and a second LSS at sector 8 and that both of these LSS would have a crab cavity: one crab cavity at the downstream of sector 6, and the second at the upstream end of sector 8. Both sectors 6 and 8 would not be SPX sectors–the bunch length for those sectors would be the same as the rest of the storage ring. For the SPX upgrade path, the crab cavity could be moved to the opposite end of the straight section, and two sectors would then have SPX capability. It was decided to designate sector 6 as the SPX upgrade target, so that upgrade would be affected by moving the crab cavity to the upstream position on the 6-ID straight section. Note that with the crab cavities installed in LSS's at sectors 6 and 8, their undulator capacity is essentially that of a non-LSS straight section.

Combining these factors with the proposed flagship projects, the roadmap was developed that is shown in Table 3. Please note that color in this table does not indicate priority, but rather indicates that a major change is being proposed for this beamline. Likewise, those beamlines in light grey are those that are not being moved or otherwise subject to major reconfiguration, but may still be target of major upgrade investments. Bending magnet beamlines are not included in this table for clarity. There are bending magnet beamline projects listed as flagships in CD-0, but the placement of these is relatively easy due to availability of several open bending magnet ports.

Highlights of the roadmap are as follows:

- The 20-ID program will be moved to make room for long imaging beamline (AXI-WF). The LERIX and XAFS programs from 20-ID will be the featured programs of the new Advanced Spectroscopy beamline to be sited at 25-ID. 25-ID will be canted, giving each of these programs increased capacity.
- The new AXI-WF beamline will be built at 20-ID. This beamline will be 150-200 m in length and will require a new building to house the downstream station. Funding for this building is being sought from the State of Illinois as part of the Advanced Imaging Institute. A single-shot imaging station will be placed upstream (inside the experiment hall) of this beamline.
- As stated above, crab cavities will be placed on the downstream end of the 6-ID LSS and the upstream end of the 8-ID LSS. 6-ID is designated as the second potential SPX sector if a future upgrade is pursued.
- The ultrafast programs from 11-ID-D and 20-ID will be moved to 6-ID to geographically consolidate timing programs . The current 6-ID programs will be moved or consolidated into other programs.
- 32-ID will be canted to form two independent beamlines. The wide field imaging is moved to 20-ID as described above. The Bragg CDI program of 34-ID-C will move to one of the branches, the TXM (currently at 32-ID) will move to the other. A second single-shot imaging program is also placed on this beamline. The single-shot imaging is limited to hybrid mode in the storage ring, and the placement of two separate facilities (which will be optimized for different aspects) will allow for more capacity in this area during the fraction of time the storage ring is in this mode.
- The 2-ID microdiffraction program will move to 34-ID, due to synergy with the 3DXRD programs. Note that 34-ID is currently undergoing a cant (ARRA funding).
- The 2-ID beamline will be canted with one branch dedicated for application of Fresnel CDI and the second for microfluorescence.
- Liquid scattering from 6-ID, 9-ID, and 15-ID will be consolidated at a newly canted 15-ID beamline. Please note that 15-ID is operated by ChemMatCARS, and that the CARS management has agreed that such an arrangement might be viable. Obviously, extensive negotiations between the APS, CARS, and 6-ID and 9-ID liquid scattering stakeholders will need to be pursued if this proposal is to move forward.

Table 3 APS Proposed Roadmap Configuration

Beam line	Owner	Current	Long Strt.	Cant	Long BL	Proposed Map
1-ID	XOR	HE Stress Strain Texture HE Diff. Microscope / µPDF	x	x		D: HE Stress Strain Texure E: HE Diff. Microscope
2-ID	XOR	B: CDI / µFluorescence D: µDiffraction / µFluorescence E: µFluorescence		x		B: CDI / µFluorescence D: µFluorescence E: µFluorescence
3-ID	XOR	NRS/HERIX				NRS/HERIX
4-ID	XOR	C: LE Magnetic Spectroscopy D: HE Mag. Spect / Mag Diffrac.		x		C: LE Mag. Spectroscopy D: HE Mag. Spectroscopy
5-ID	DND-CAT					DND-CAT

6-ID	XOR	B: Magnetic Diff./General Diff. C: Surface/Liquid Scattering D: HE Scattering	x			Time-resolved EXAFS (program from 11-ID and 20-ID)
7-ID	XOR	Time-resolved		M		Time-resolved/SPX
8-ID	XOR	XPCS & Coherent SAXS	x		M	XPCS & Coherent SAXS
9-ID	XOR	MERIX/Liquid Scattering				MERIX
10-ID	MR-CAT					MR-CAT
11-ID	XOR	B: PDF C: PDF/HEX D: TR-XAFS	x	x	M	B: PDF C: PDF/HEX D: In-field diffraction (mag scat.)
12-ID	XOR	SAXS/surface diffraction		*		SAXS/surface diffraction
13-ID	GSECARS	GSECARS	M	*		GSECARS
14-ID	BioCARS	PX/Ultrafast				PX/Ultrafast
15-ID	ChemMatCARS	Single Crystal/Liquid Scattering/USAXS		x		Single Crystal /USAXS / Liquid Scattering (9-ID & 6-ID pgms)
16-ID	HP-CAT	HP	M	*		HP CAT
17-ID	IMCA-CAT	PX				PX
18-ID	BIO-CAT	BIO-CAT				BIO-CAT
19-ID	SBC-CAT	PX				PX
20-ID	XOR/PNC	XAFS/TR-EXAFS/Surf./LERIX			x	Wide Field & Single Shot Imaging (AXI proposal)
21-ID	LS-CAT	PX		*		PX
22-ID	SER-CAT	PX				PX
23-ID	GM/CA-CAT	PX		*		PX
24-ID	NE-CAT	PX		*		PX
25-ID				x		EXAFS/LERIX
26-ID	CNM/XOR	Nanoprobe				Nanoprobe
27-ID					x	New Proposal (Dyn. Comp. or Nuclear & Rad. Research)
28-ID			x	x	x	X-ray Interface Science (XIS)
29-ID	XOR/IEX	LE Spectroscopy				LE Spectroscopy
30-ID	XOR	HERIX/MERIX				HERIX
31-ID	LRL-CAT	PX		x		PX
32-ID	XOR	Single Shot Imaging/TXM Wide Field Imaging		x		Single Shot Imaging/TXM Bragg Coh.Diff. Imaging
33-ID	XOR	Interfaces/Diffraction	x			Interfaces/Diffraction
34-ID	XOR	C: Bragg Coh. Diff. Imaging E: 3D X-ray diffraction		*		µDiffraction (from 2-ID) 3D X-ray diffraction

	LSS location
x	LSS installed
M	LSS installed Maybe

*	Existing Canted FE
x	New Canted FE
M	Maybe

- The XIS proposed beamline will be built at 28-ID. Surface science chambers at 6-ID and 20-ID will need to be incorporated into the XIS or 33-ID beamlines.
- The MERIX program on 30-ID will be combined with the MERIX program on 9-ID to form a dedicated MERIX facility.
- The HERIX program will expand to use all of 30-ID.
- 1-ID will be canted to expand the capacity of high-energy x-ray scattering. One branch will be used for stress/strain/texture polycrystalline measurements, with an emphasis on *in situ* conditions and processing. The

second branch will be used for the HEDM program and general high-energy diffraction (including the programs from 6-ID).

- The in-field diffraction program of 6-ID and 4-ID will move to 11-ID-D. The "big magnet" instrument that has been proposed would be cited on this beamline. This project is not currently part of the APS Upgrade proposal and would require additional funding. It would require a long beamline that would extend outside the experiment hall.

The initial implementation of LSS would be at sectors 1, 6, 8, 11, 13, 16, 28, and 33. The other sectors falling on LSS symmetry locations would be implemented as pseudo-LSS (described above) and could be converted to LSS in the future if that is desirable and funding is available. The rationale for the chosen sectors is as follows:

- Sector 1 is dedicated to x-ray energies above 50 keV. In this energy range, use of multiple, short-period insertion devices provides substantial gains in brilliance/flux (far more than proportional to the linear increase in straight section length). With the canting of the sector, the extra length is needed to add an extra undulator for one branch and still allow the multiple undulators on the other, preserving 1-IDs unique capability at the APS for complete spectral coverage above 50 keV.
- As described above, if the SPX project is sited at 7-ID, sectors 6 and 8 would be severely compromised without LSS.
- Currently, Sector 11 has three branches, two of which operate above 50 keV. These beamlines share two undulators. 11-ID is slated for a cant to increase the independence of the branches, and the LSS would allow each branch to have its own insertion device.
- Sectors 13 and 16 are both planned to be canted in the near future using ARRA funds, and a LSS will allow them to take better advantage of the cant. Both of these sectors are operated by CATs (GSECARS and HP, respectively), and the management of these beamlines will be consulted to make sure that a LSS is agreeable to them.
- Sector 28 is designated as the future home for the XIS beamline. This beamline has several branches and will need canting. It will greatly benefit from an LSS to have an additional ID.
- Although not listed on the roadmap table, Sector 33 is being considered for a home to house displaced surface chambers from other beamlines and may be canted if that is done, and hence would be a good choice for a LSS. If not canted, the LSS selection of 33 would be revisited.

There are many possible variations on the proposed roadmap, some of which we list here:

- Keep the current sector 20 LERIX and XAFS programs where they are (with a new sector 20 cant), move SBC to sector 25, and place the long beamline (AXI-WF & Single Shot Imaging) on sector 19.

- Configure sector 20 as described and move BioCAT to sector 25 (or other open location) and the long beamline and place the AXI-WF long beamline on sector 18. This would also require changes to the LSS symmetry due to the incompatibility of RHB and the LSS that would fall at sector 18.
- Keep the TR-EXAFS program at 11-ID-D and dedicate sector 6 to the in-field diffraction (including possible big magnet) program.
- Swap around programs slated for the currently open sectors (sectors 25, 27,and 28.
- Consolidate some of the PX programs to liberate a beamline/sector through canting a currently un-canted sector.
- Establish partnerships between the XSD and CATs to build out unutilized hutches or develop beamlines on canted FEs. This could help free up space to allow other development opportunities.

The effort to establish the best possible APS roadmap is an ongoing effort. Several aspects are in flux and may effect the configuration of the roadmap.

- Accelerator studies continue in an effort to define the possibilities for LSS symmetries. If a lattice can be designed that will allow symmetry breaking, it would make possible a wider range of LSS placement scenarios.
- The APS is exploring partnership options with CATs to allow possible beamline moves and possible consolidation of programs.
- One sector is being set aside in anticipation of successful funding efforts by non-APS groups seeking to build a beamline. If these efforts do not succeed, the open sector will be used as part of the upgrade.
- The SPX project is current sited at 7-ID. Alternate scenarios are being considered.
- We continue to look for a program that could share 35-ID with the accelerator diagnostics.
- A variety of technical issues have been pointed out by both APS staff and users since the release of the roadmap. We are working through these issues for satisfactory solutions. Refinements to the roadmap will need to address these issues.

Summary

In summary, the APS Roadmap that was released should be considered as a first draft with a goal of creating a comprehensive beamline configuration consistent with the major goals of the APS Upgrade. As the roadmap evolves, it will guide future developments, both within and outside of the APS Upgrade project and will serve, we hope, as one of the focal points for continued involvement of the user community in the APS Upgrade that is so vital for the future of the APS.